

Headquarters U.S. Air Force

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Rapid Adaptive Site Characterization: Techniques for Discerning Contaminant Spatial Variability and Geological Heterogeneity



U.S. AIR FORCE



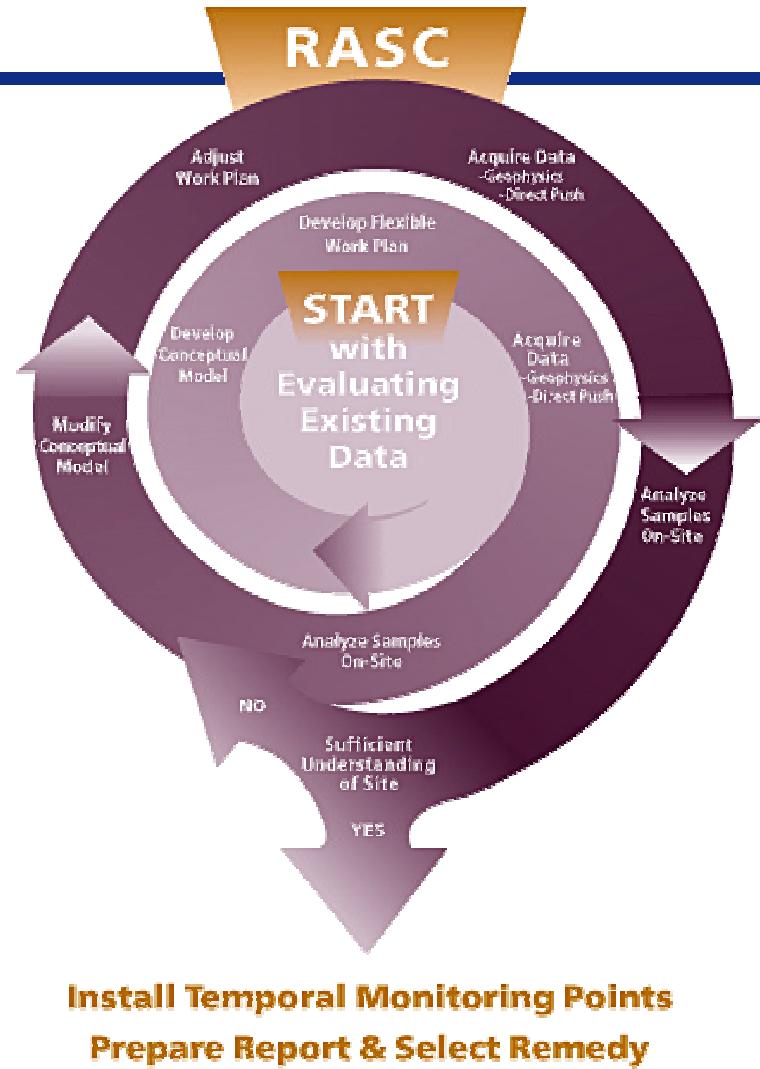
Acknowledgements

- John Cherry – University of Waterloo
- Bob Ingleton - University of Waterloo
- Mette Broholm – Danish Technical University
- Richelle Allen-King – Washington State University
- Paul Daly – Precision Industrial Maintenance
- Don Maynard – The Johnson Company



What is RASC?

- An in-field process involving an iterative feedback and response cycle
- Investigation Altered in Progress Based on an Assessment of Incoming Data
- Sufficient Quantity of Scale-Appropriate Data





The Problem

- Remedies that don't work due to lack of understanding
- Site investigations that don't provide sufficient understanding
- Hydrogeology: Historical Perspective



The Conventional Investigation

- **Expensive and Time Consuming**
 - Many mobilizations
- **Sparse Data Collection**
 - Use of Monitoring Wells
 - Expensive Analytical Techniques
- **Little Attention to Vertical Variability**
- **Not Scale Appropriate**



What Your Monitoring Well is Not Telling You...

- Long-screened wells provide depth-integrated, flow-weighted average concentrations Gibbs et. al., 1993. Ground Water Vol. 31 No. 2

$$C_m = \frac{\sum_{i=1}^n C_i Q_i}{\sum_{i=1}^n Q_i}$$

- “a long screened well is one that has significant physical and chemical heterogeneity in the aquifer along its length” Reilly and LeBlanc, 1998. Ground Water Vol. 6 No. 4



Plume Distortion and Apparent Attenuation Due to Concentration Averaging in Monitoring Wells

By James M. Martin Hayden and Gary A. Robbins
Ground Water Vol 35, No. 2 March-April 1997

- Estimate of plume extent ranged from 0% of actual for 4 m screens in low K aquifer to 90% using 1 m screens in high K aquifer
- Inconsistent well design and purging procedures caused spurious directional skewing, bifurcation, and zones of low concentration
- Calibrating a model to the well data resulted in calculated R of up to 23 though there was no retardation in the plume.
- Determination of a decay constant from well data yielded a half life of 45 days though there was no degradation in the plume



Site Investigation and the Scale of Inquiry

- Natural heterogeneities require a fundamentally different approach.
- The scale of sampling must be appropriate to the scale of heterogeneities.



Factors Necessitating Detailed Sampling

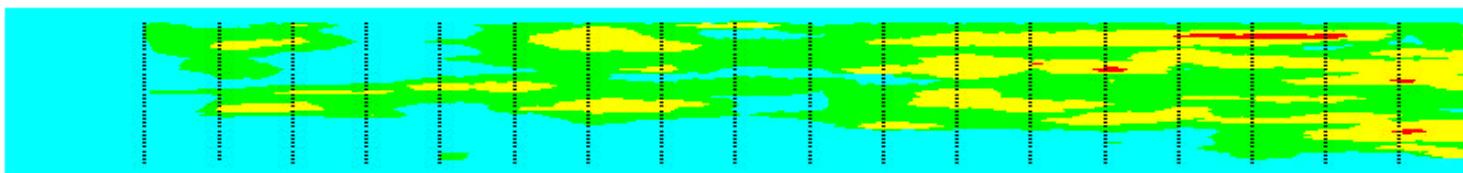
- Hydraulic Conductivity Variability
- Weak Transverse Hydrodynamic Dispersion
 - Steep Vertical Concentration Gradients
- Heterogeneous Distribution of DNAPL Sources



“Homogeneous” Sand Borden, Ontario



Distribution of -Ln K in Borden Sand from Sudicky, 1986



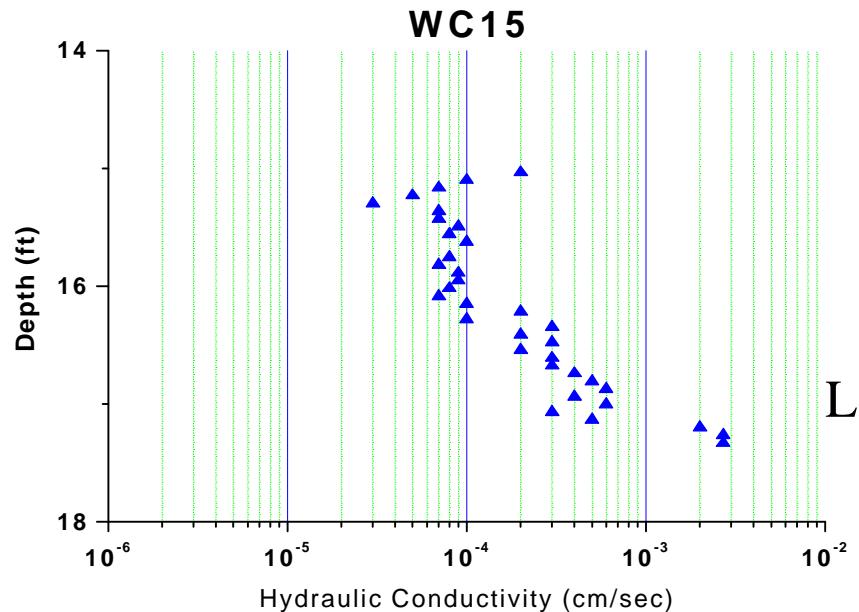
- 1279 K measurements
- Mean $K = 9.75 \times 10^{-3}$ cm/sec
- Range = one order of magnitude
- Values typically vary by a factor of 5



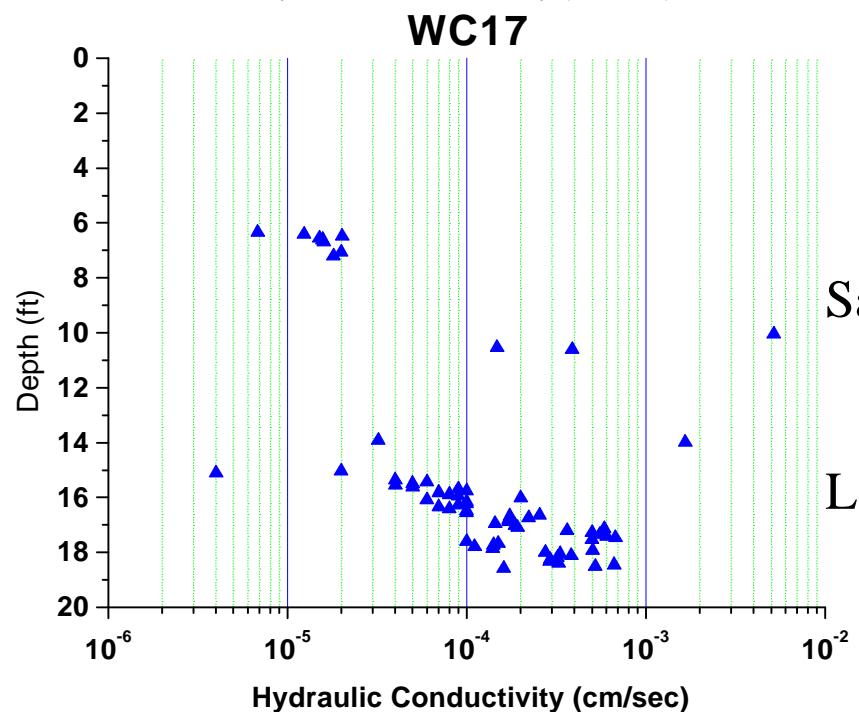
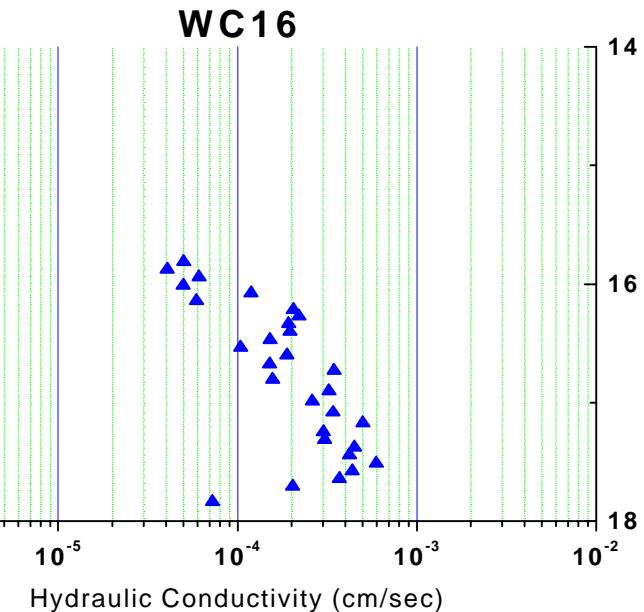
Hydraulic Conductivity Correlation Lengths

<i>Location</i>	<i>Horizontal Correlation Length (m)</i>	<i>Vertical Correlation Length (m)</i>	<i>Investigator</i>
Borden, Ontario	2.8	0.12	Sudicky (1986)
Otis, ANGB	2.9 - 8	0.18 – 0.38	Hess et al (1992)
Columbus AFB	12.7	1.6	Rehfeldt et al
Aefligan	15 - 20	0.05	Hess et al (1992)
Chalk River, Ontario	1.5	0.47	Indelman et al (1999)

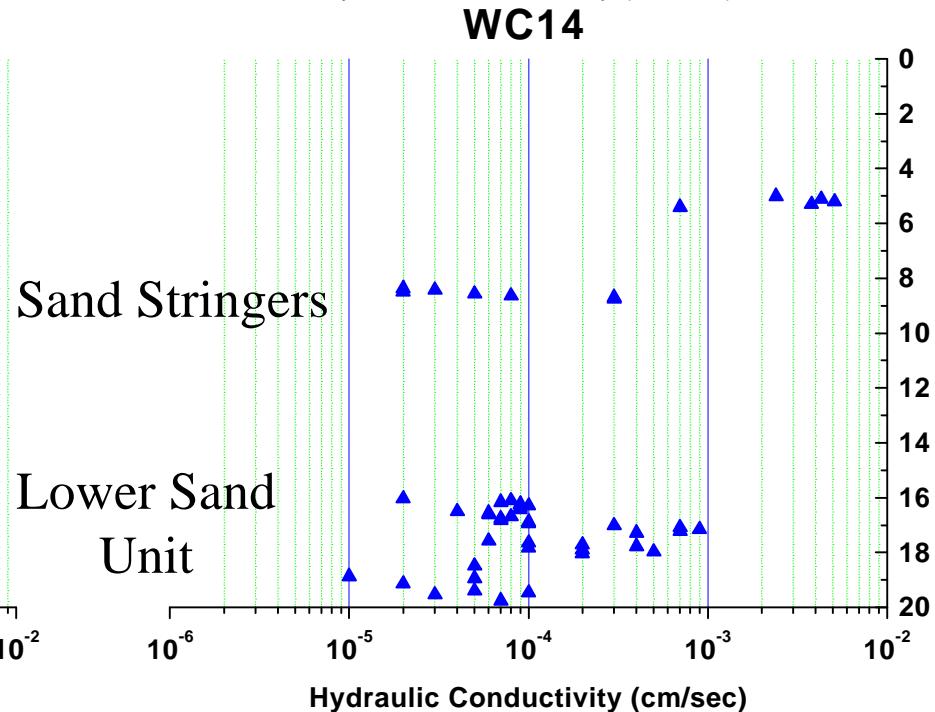
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Lower Sand
Unit



Sand Stringers
Lower Sand
Unit

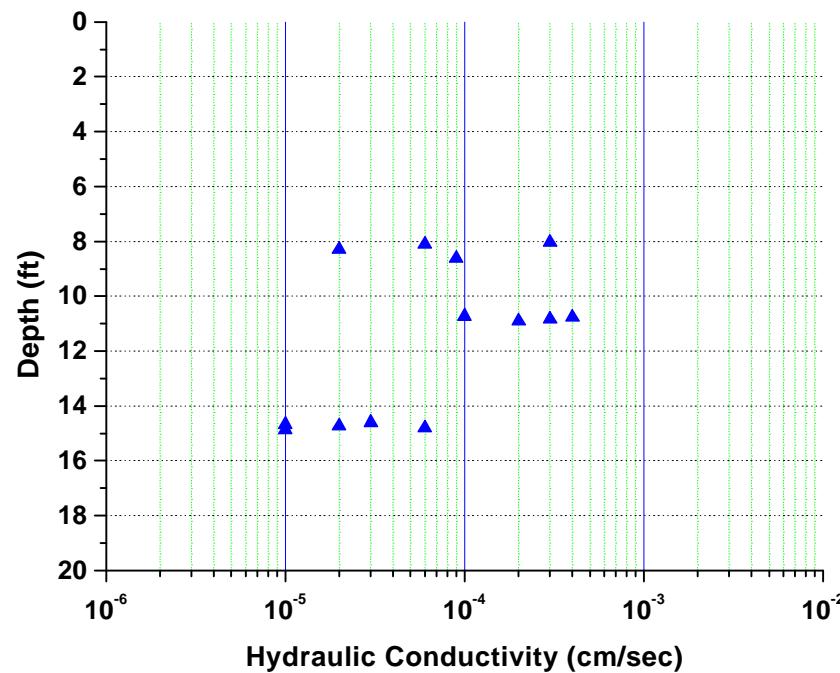




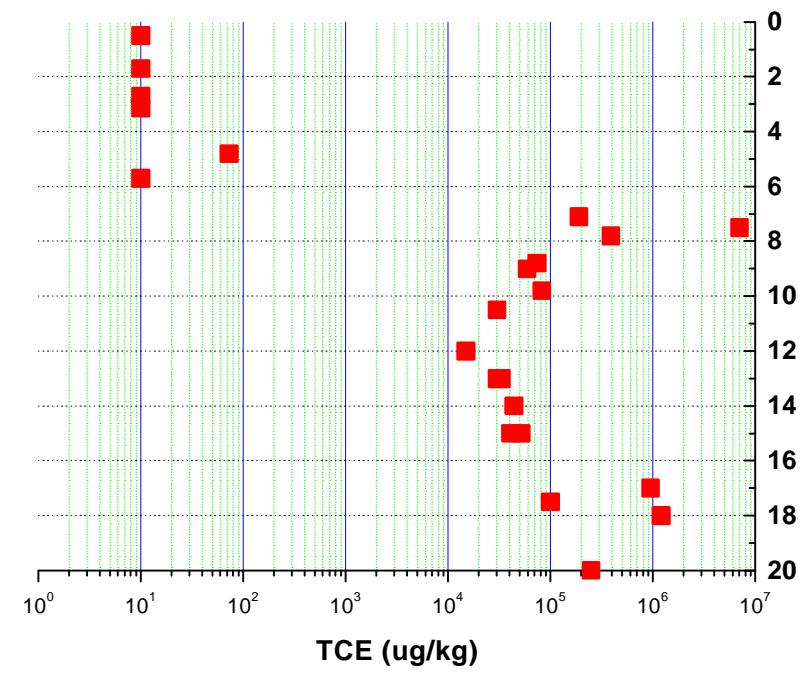
Pease AFB Site 32

Core Location WC10

Hydraulic Conductivity Variability



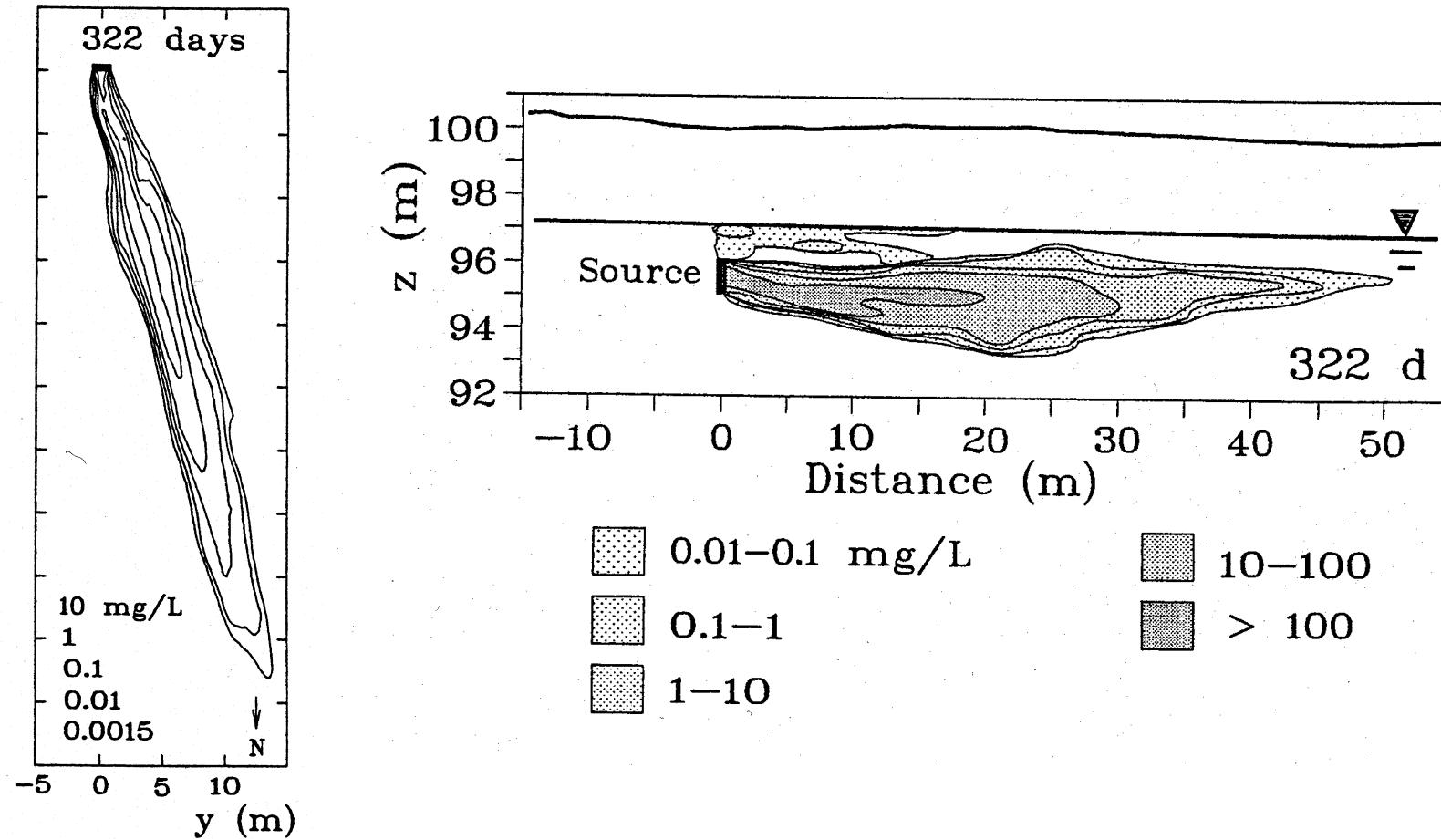
Concentration Variability



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Weak Dispersion

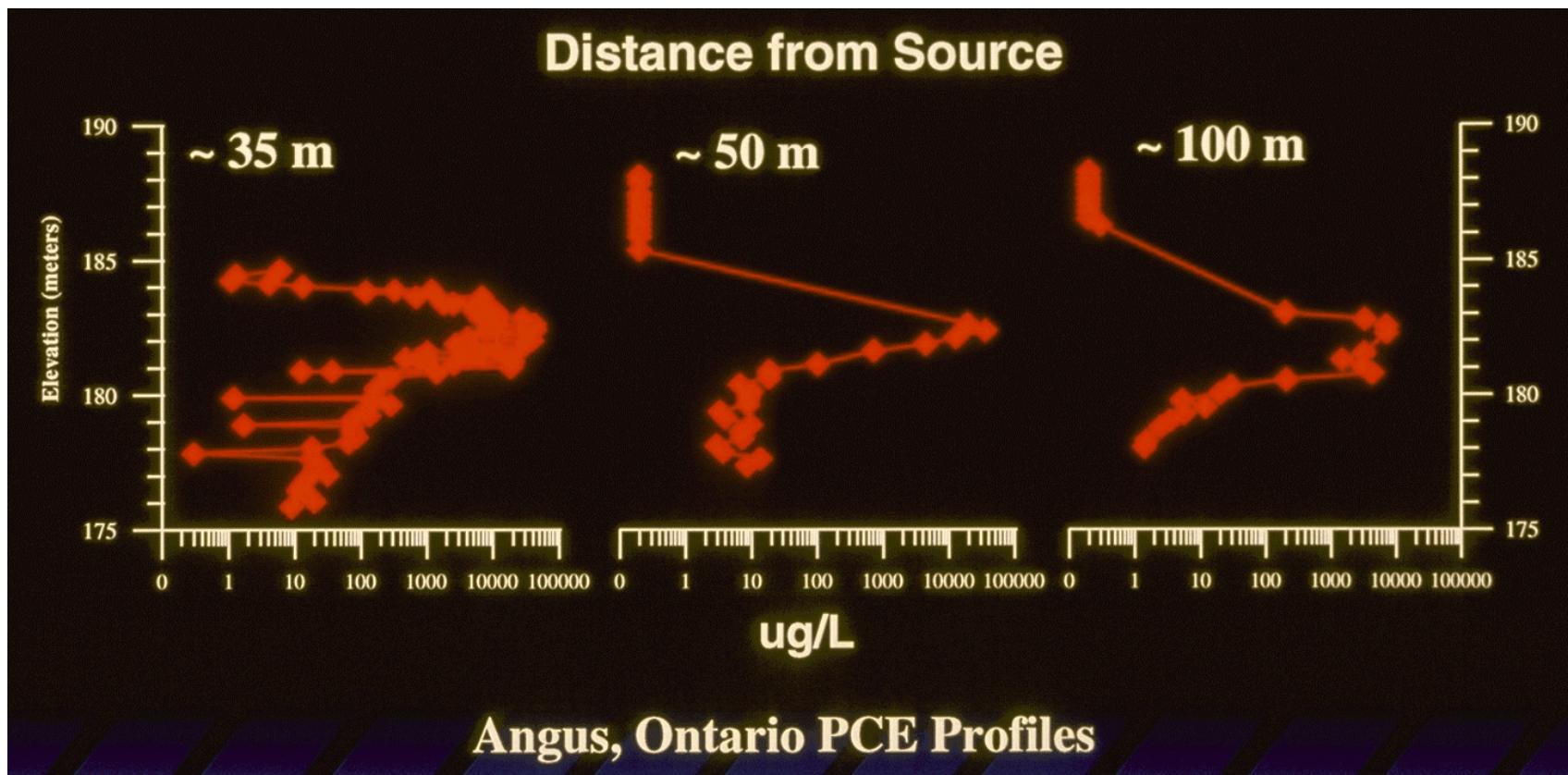


From Rivett, et. al., 1994

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Weak Dispersion/Steep Concentration Gradients



DNAPL Source Distributions

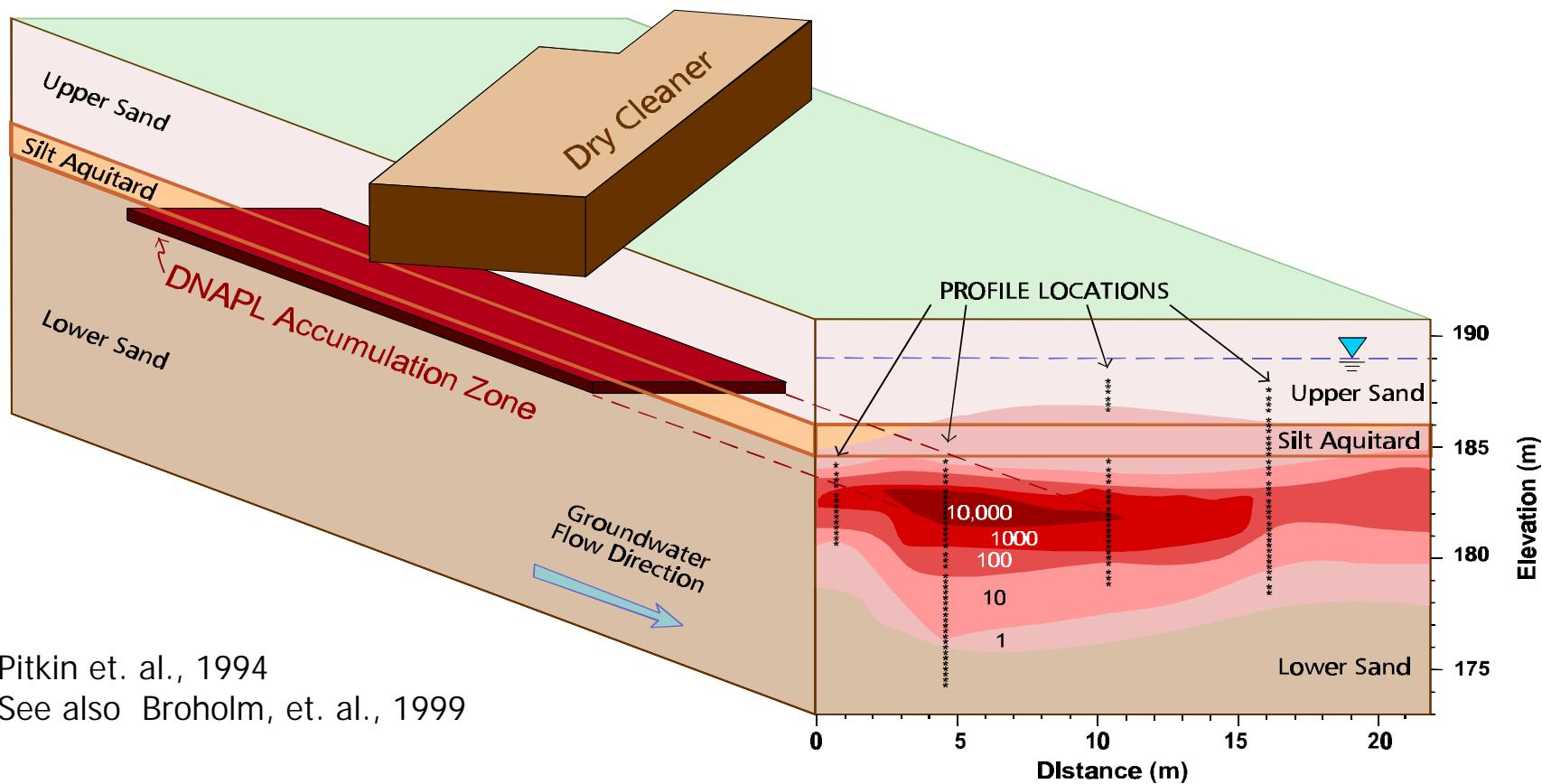
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Poulsen & Kueper, 1992



Angus Ontario PCE Plume

A Plume Suspended Below an Aquitard

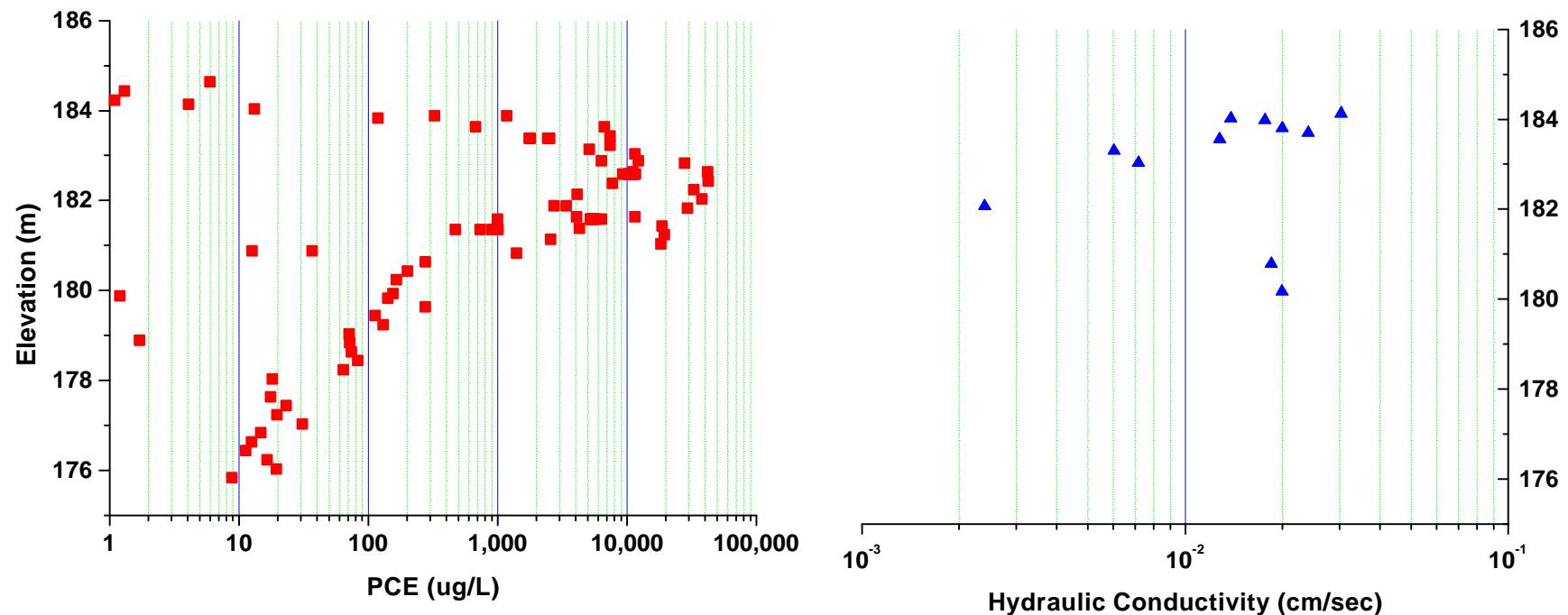


I n t e g r i t y - S e r v i c e - E x c e l l e n c e



Angus, Ontario

Lower Sand Unit



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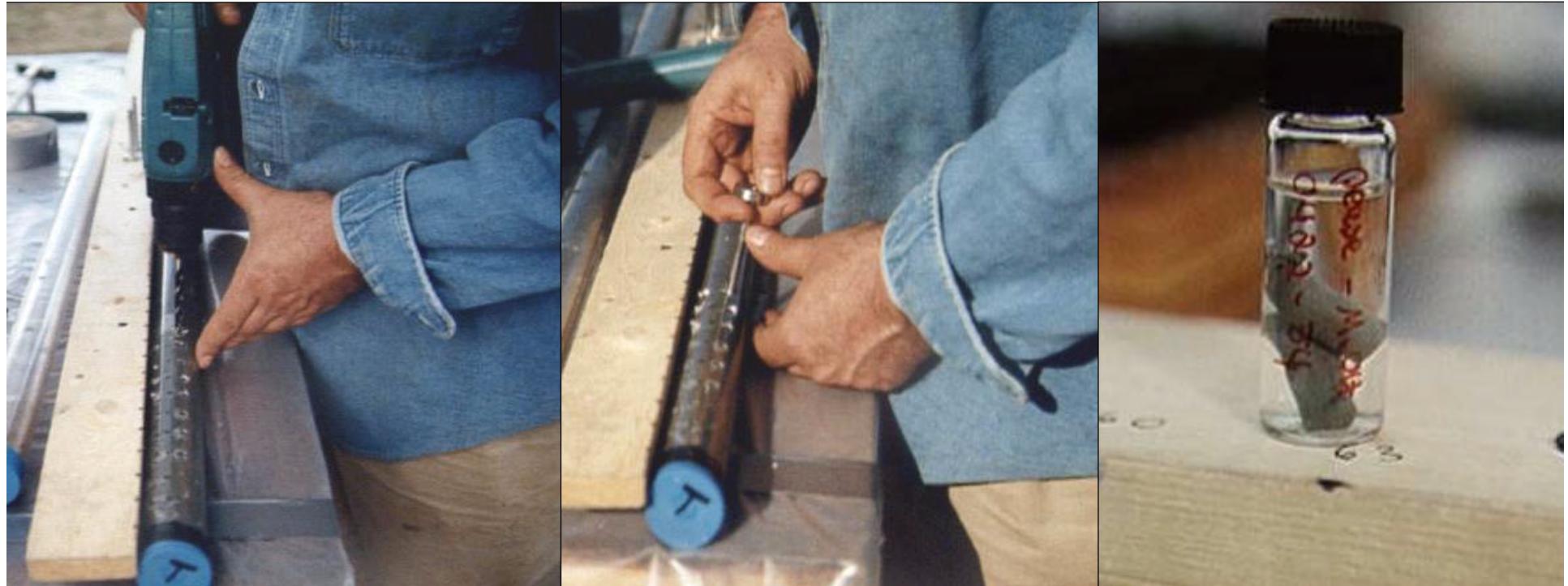
Critical Variables

- Sample Interval: *the vertical dimension of the sampled portion of the aquifer*
- Sample Spacing: *the vertical distance between samples*
- The Sampling Program Must be Appropriate to the Scale of the Natural Heterogeneities





Soil Sampling Methods

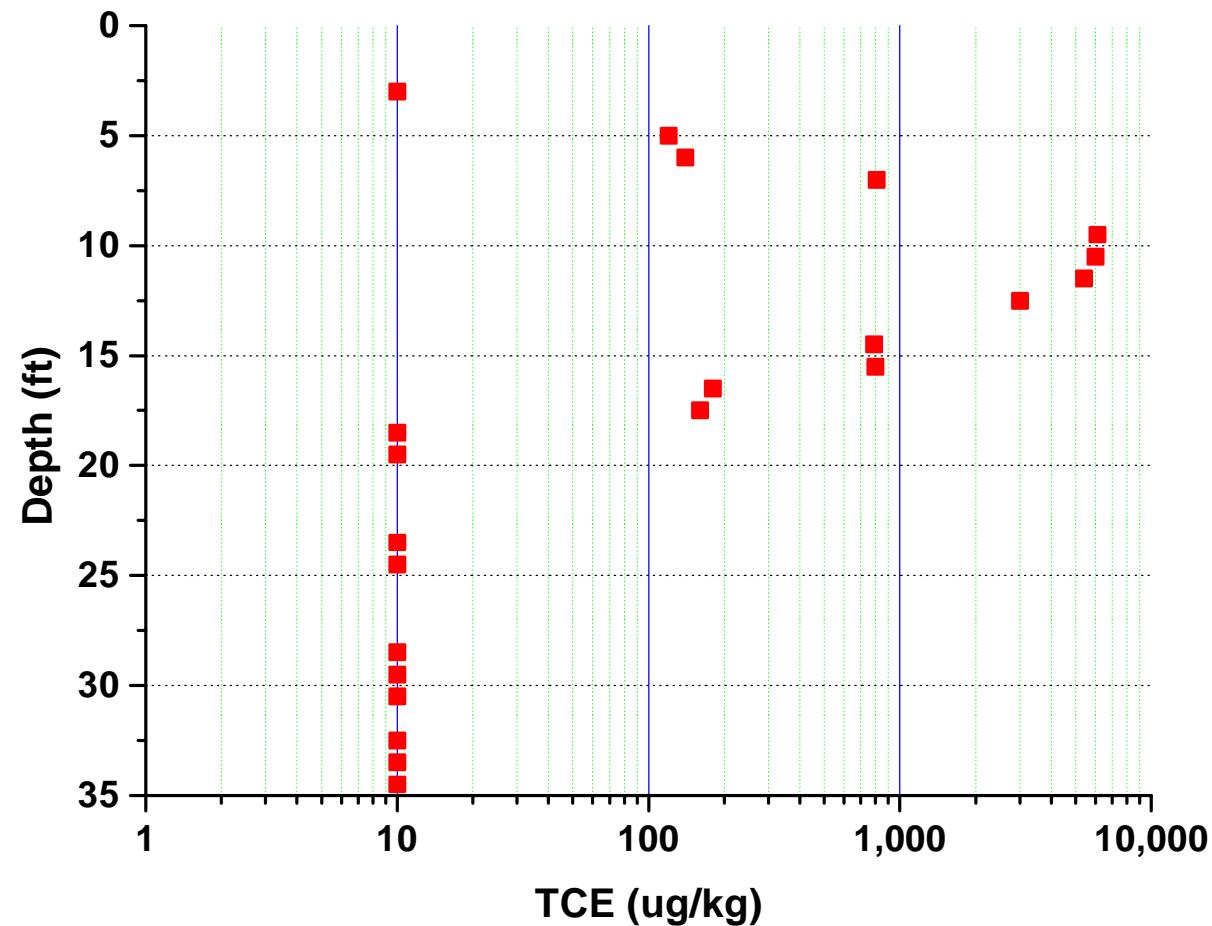


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Sample Spacing

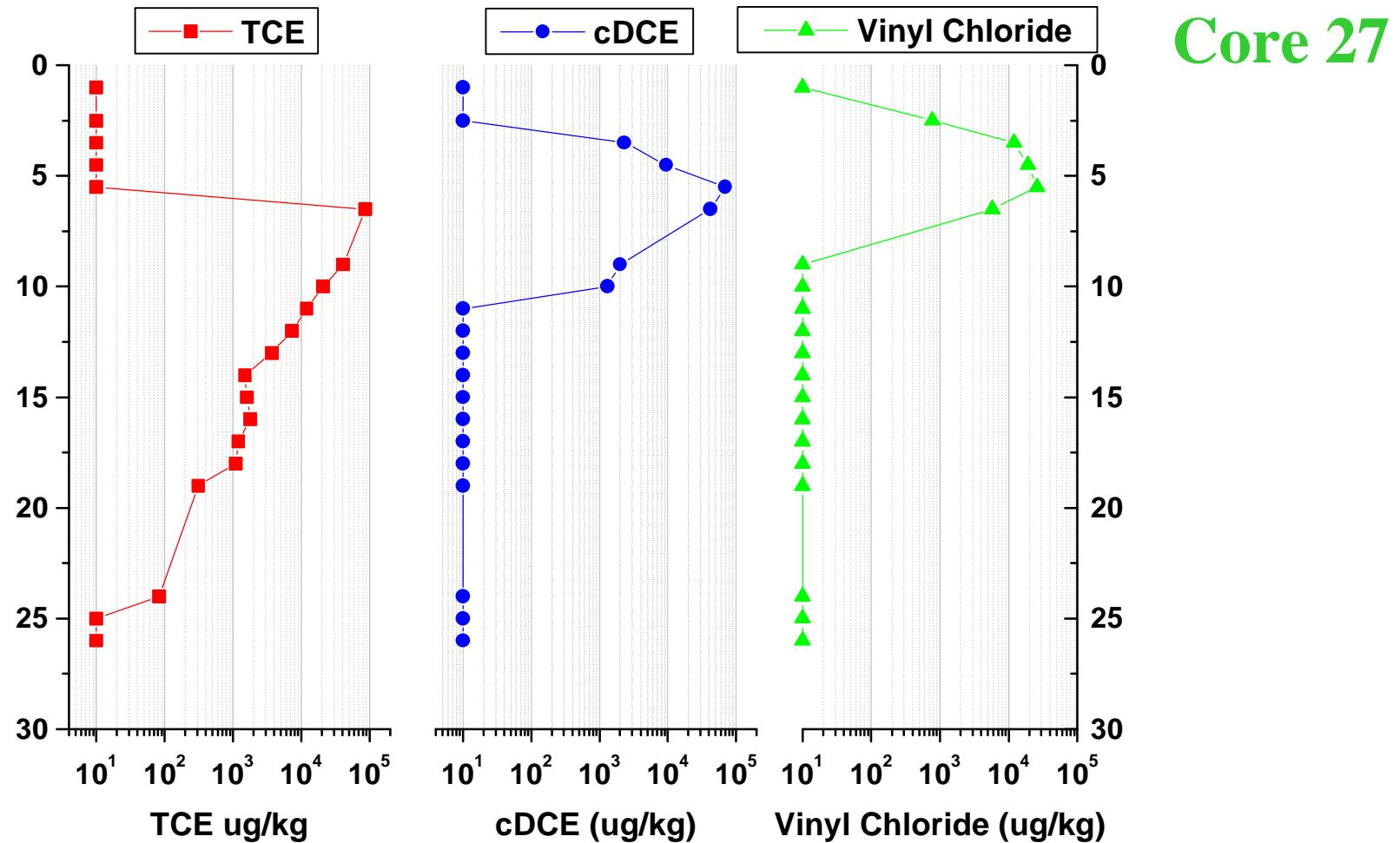
WC24 Pease AFB Site 32



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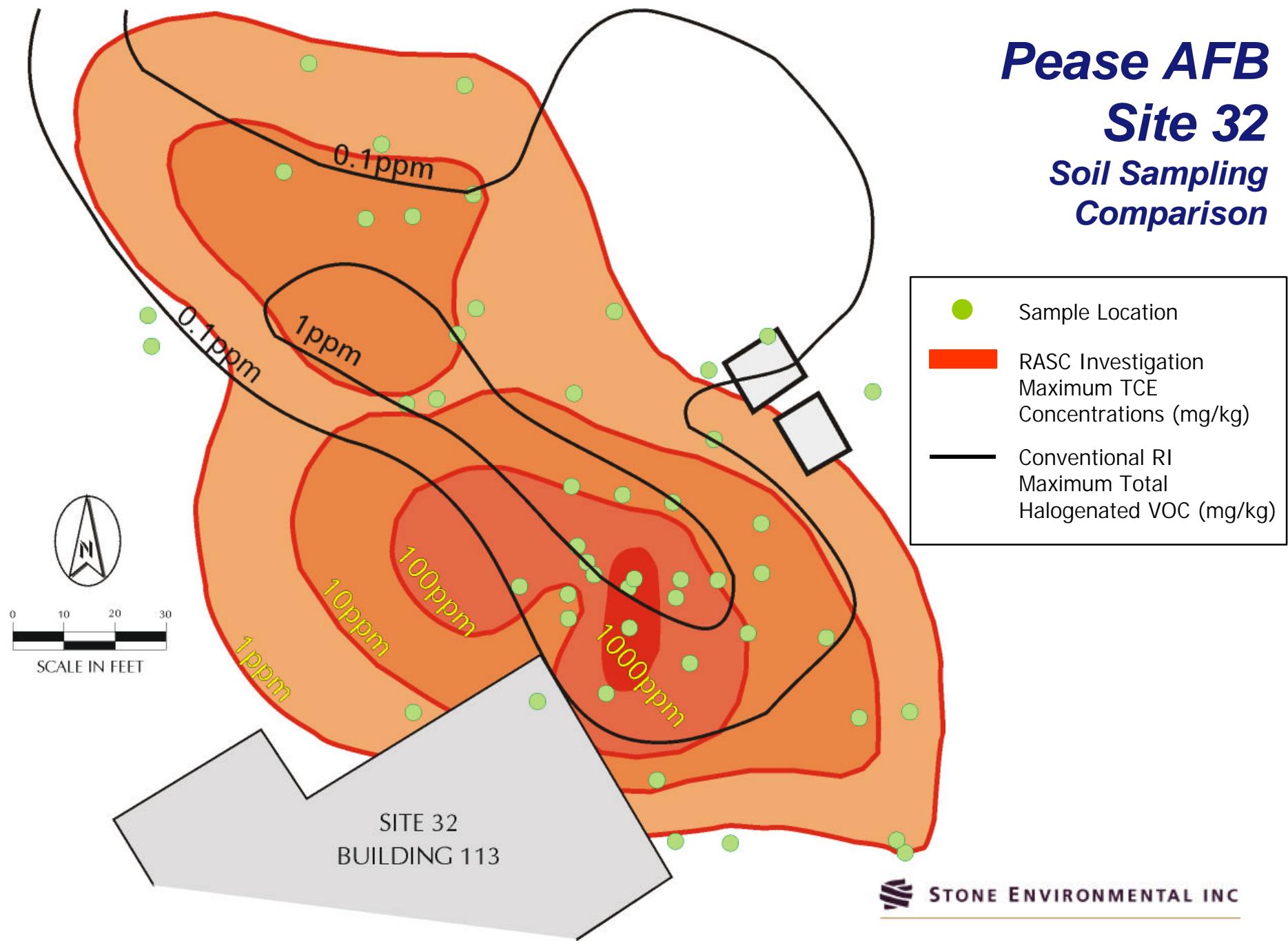
Spatial Variability in Natural Attenuation



I n t e g r i t y - S e r v i c e - E x c e l l e n c e

Pease AFB Site 32

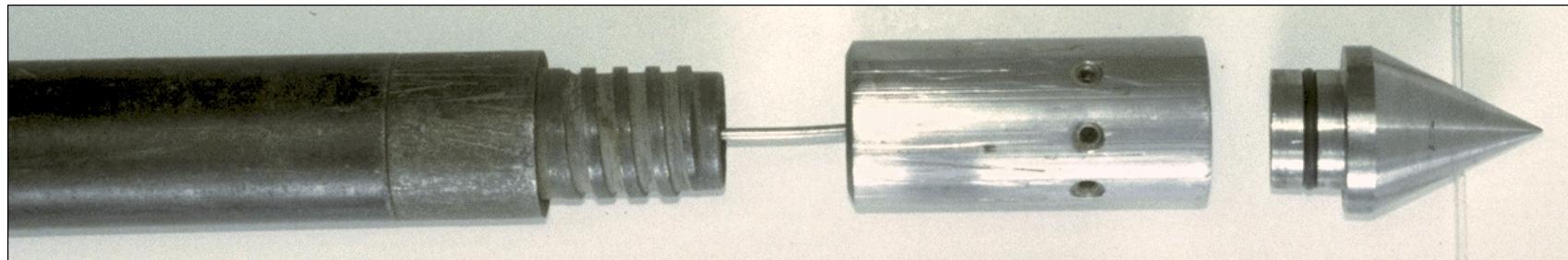
Soil Sampling Comparison





The Waterloo Profiler

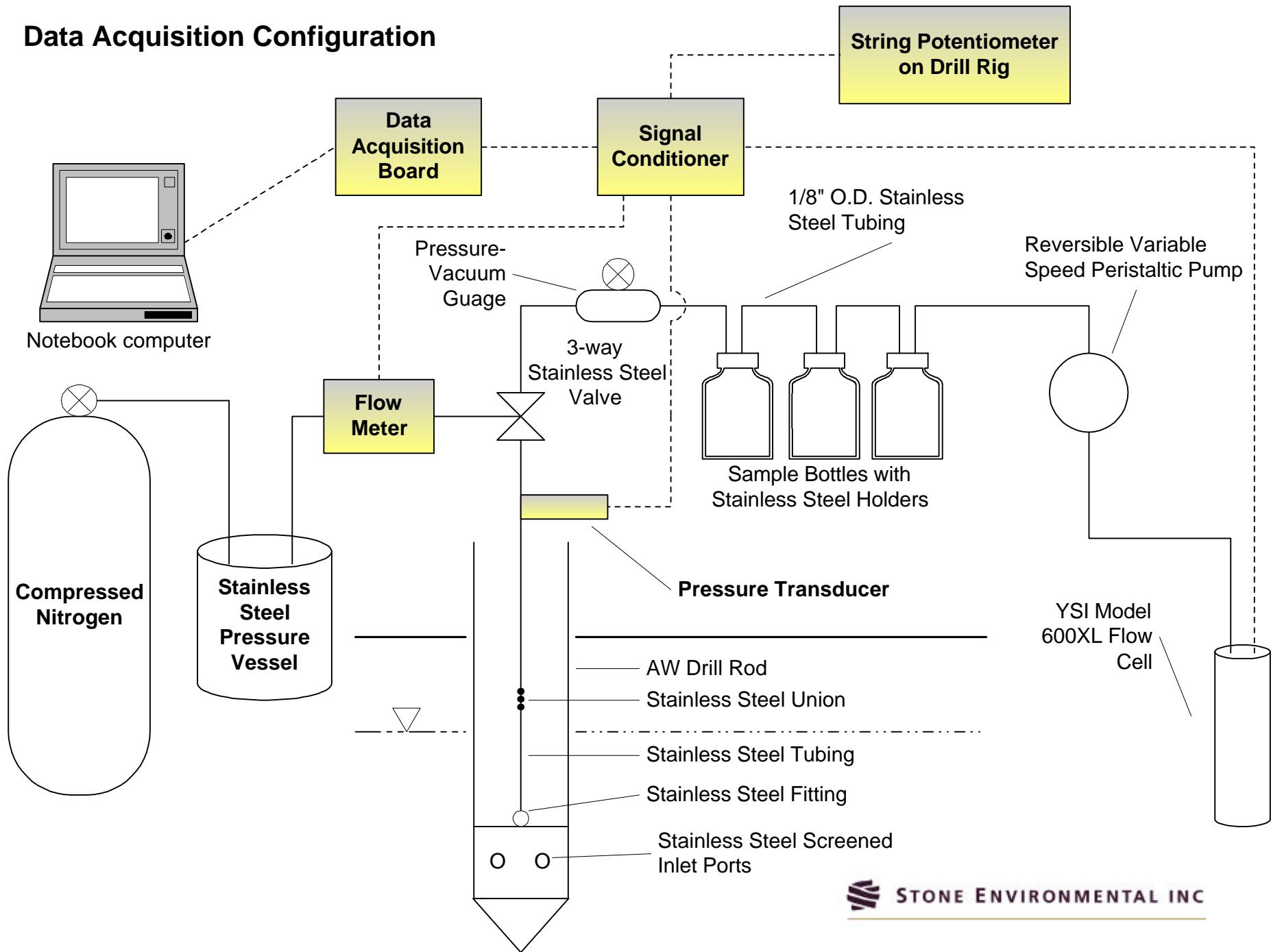
a direct push, point sample profiling tool



- **Conceived by Dr. John Cherry - University of Waterloo**
- **Prototypes Designed and Built by Robert Ingleton - University of Waterloo**
- **Development Funded by the University Consortium Solvents-in-Groundwater Research Project**

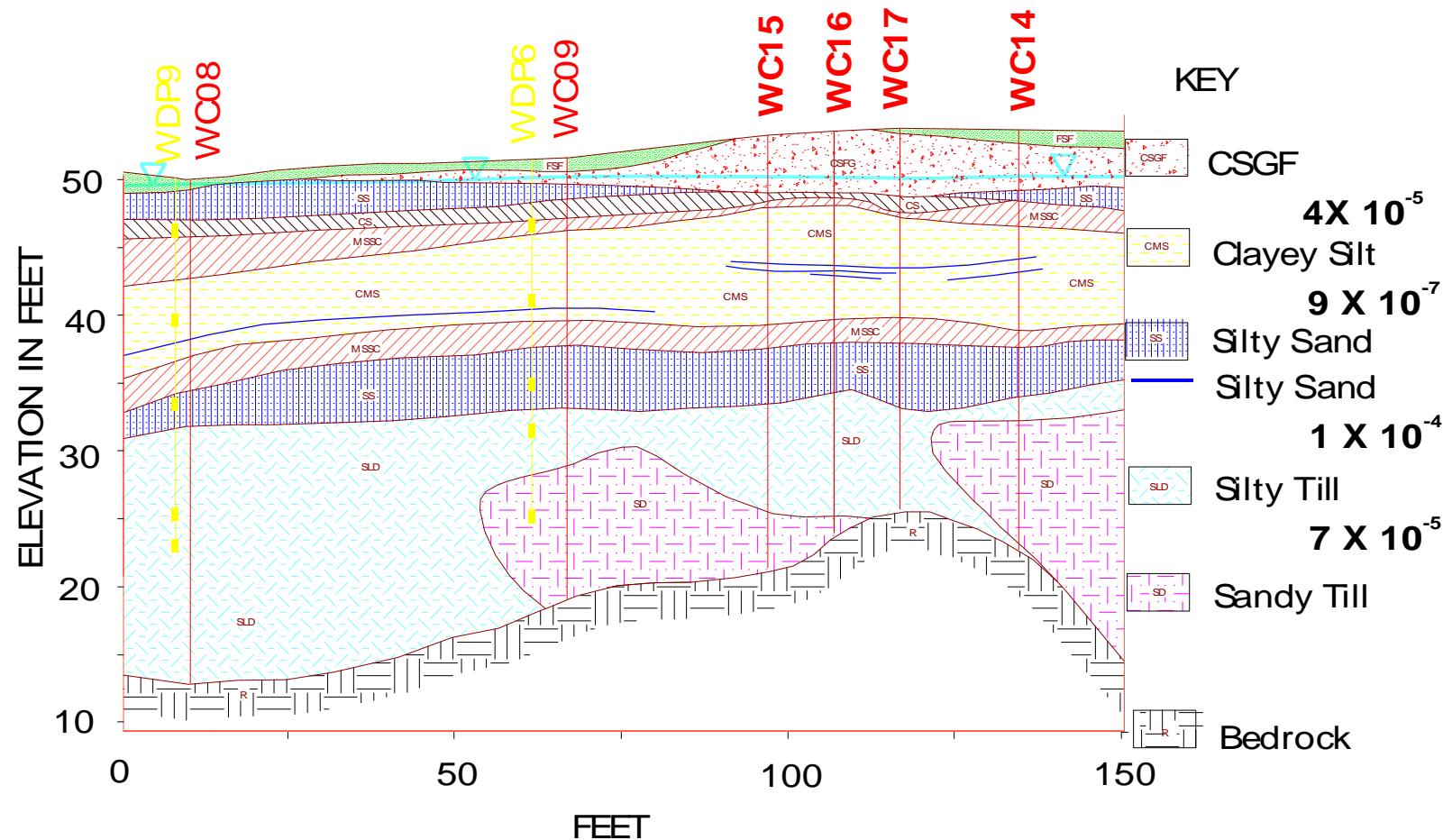
See Pitkin, et. al., 1999

Data Acquisition Configuration



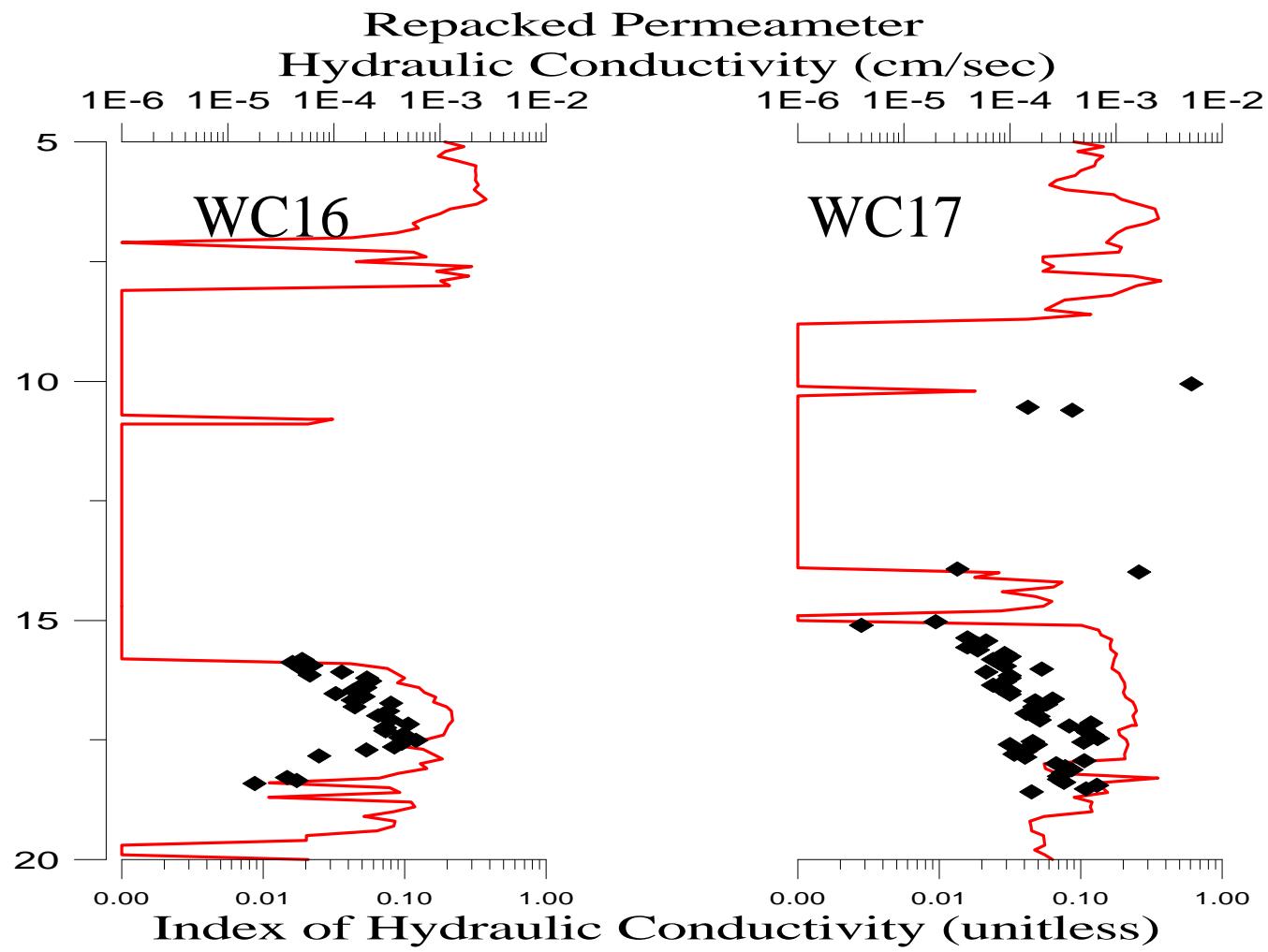


Stratigraphy at Pease Site 32

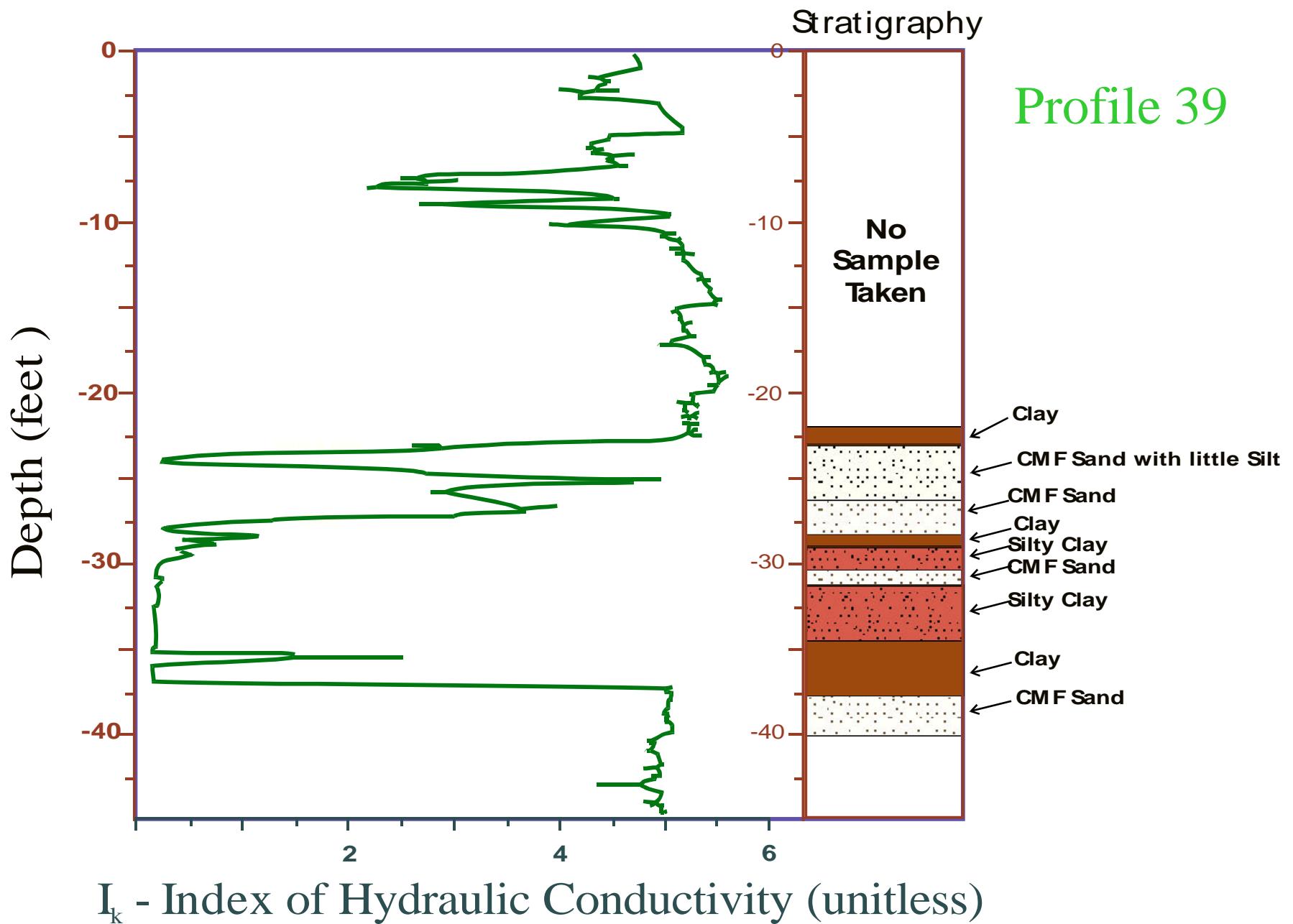




Index of K at WC16 and WC17



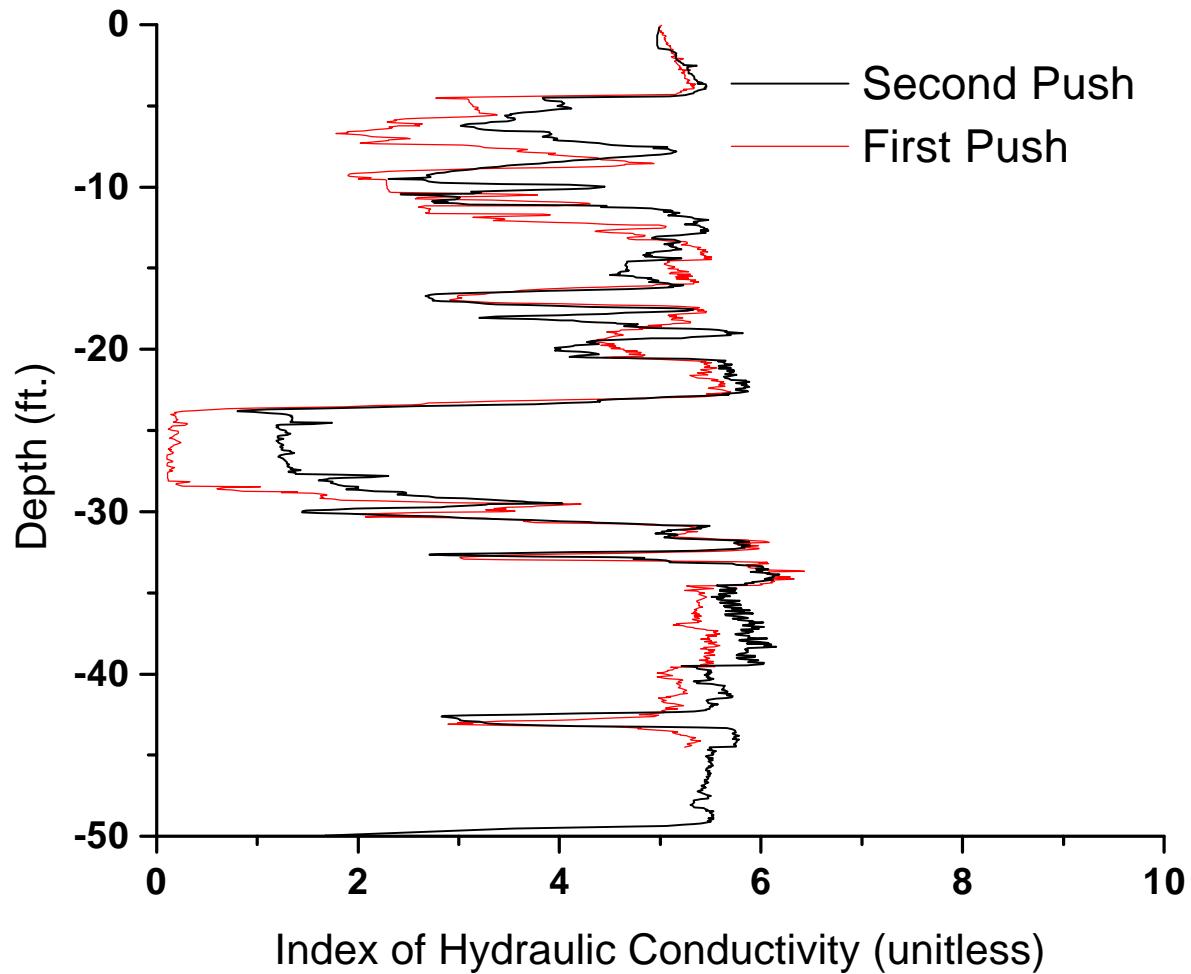
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Reproducibility: Two Pushes in the Same Hole

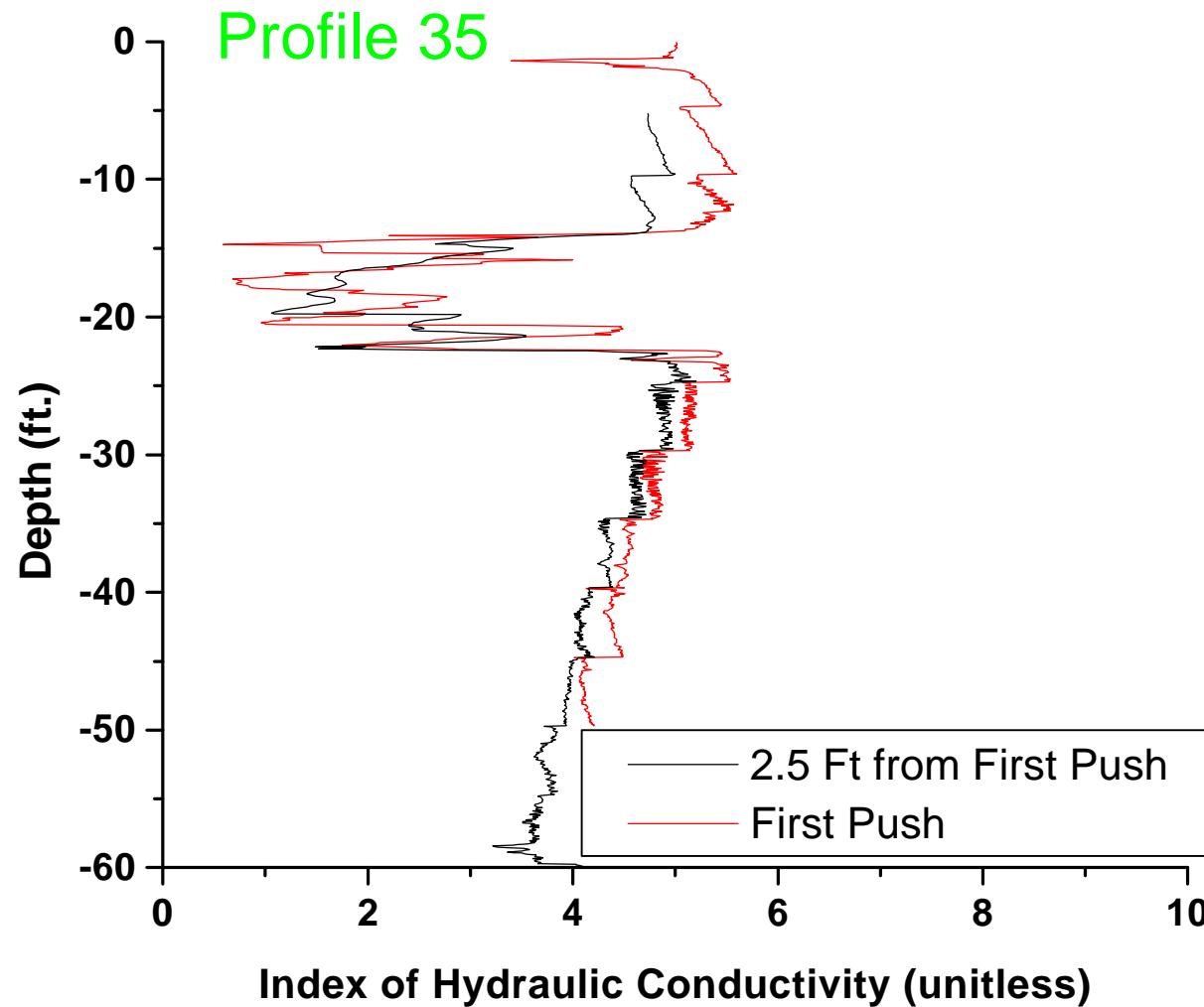
Profile 37



I n t e g r i t y - S e r v i c e - E x c e l l e n c e

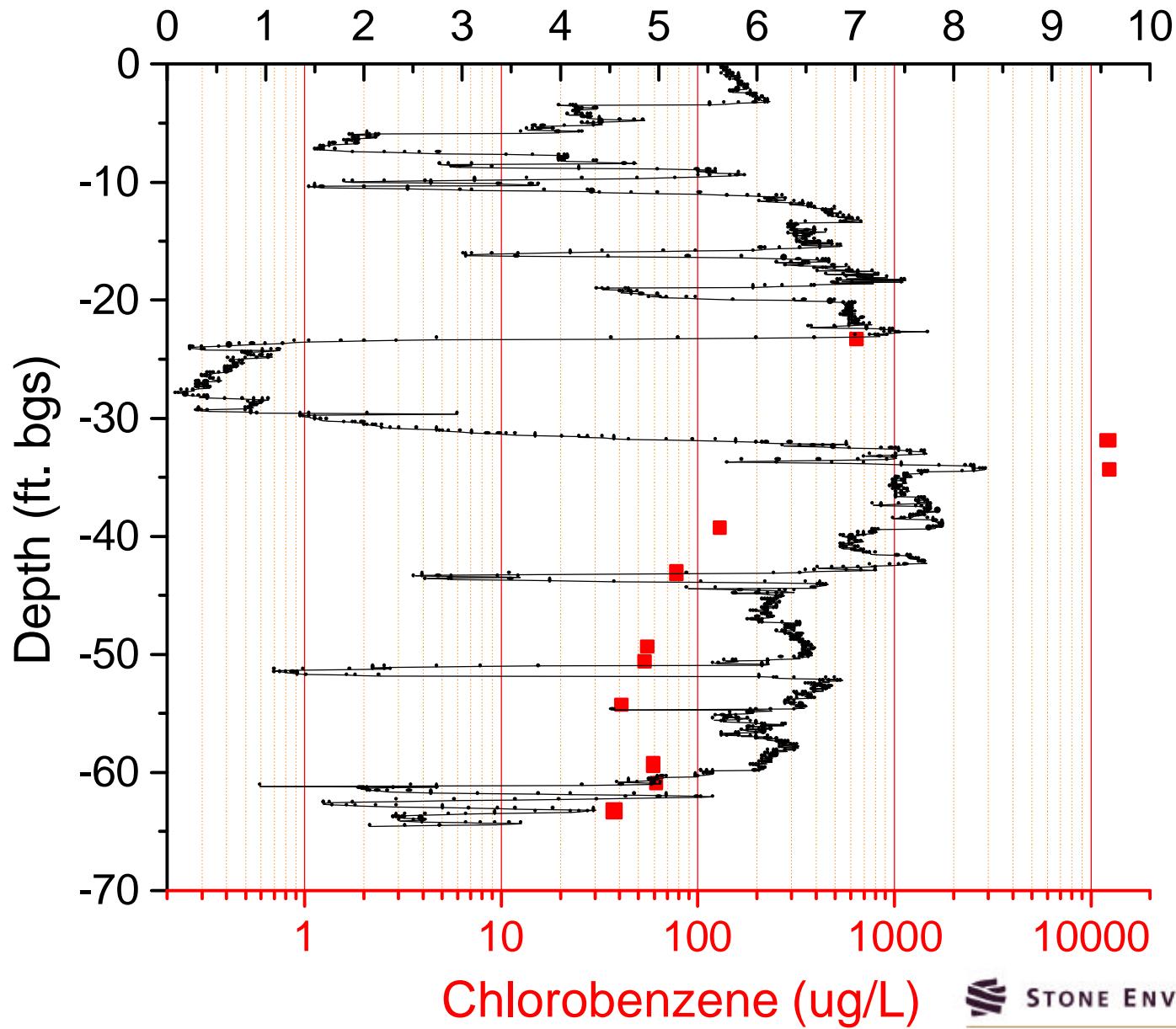


Reproducibility: Pushes 2.5 ft Apart



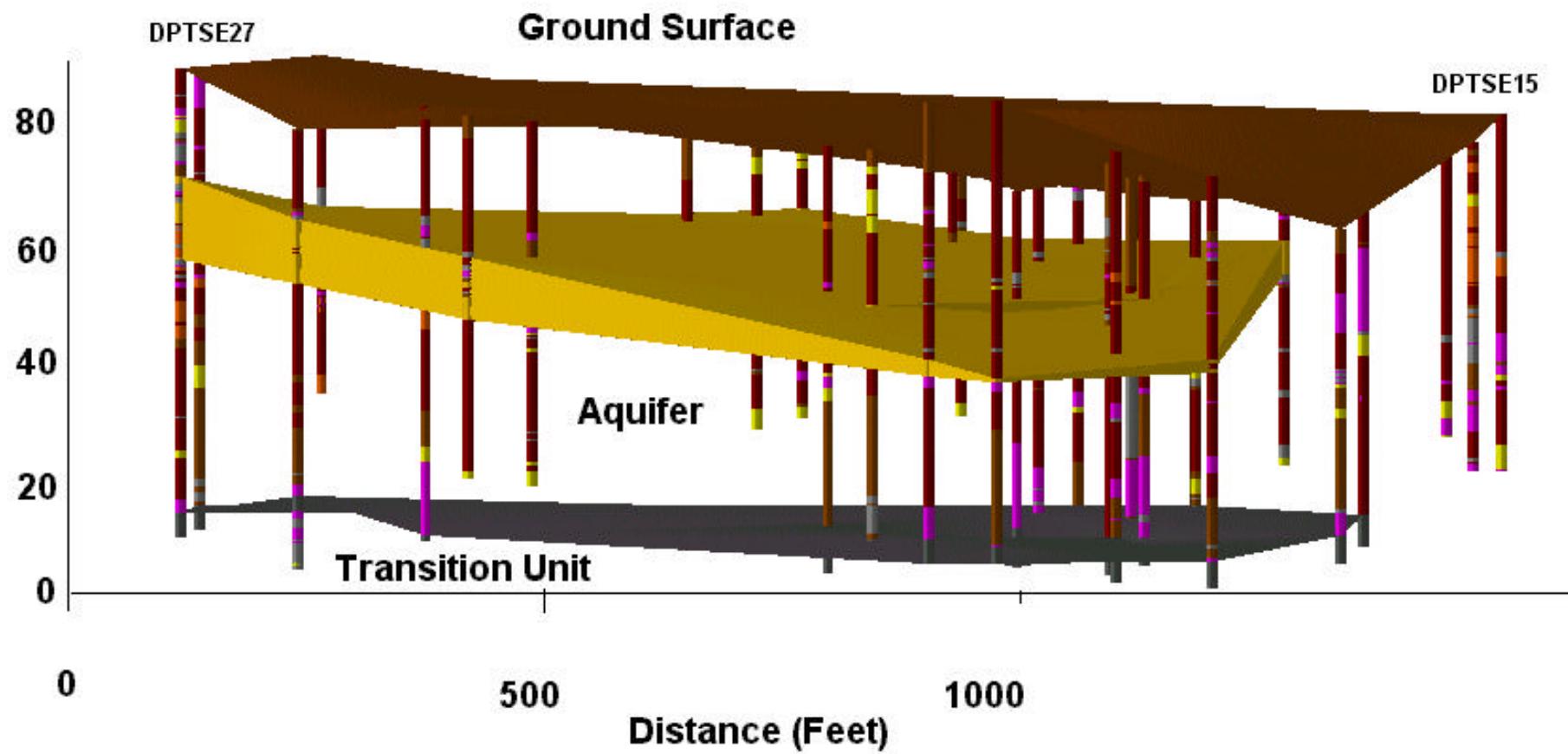
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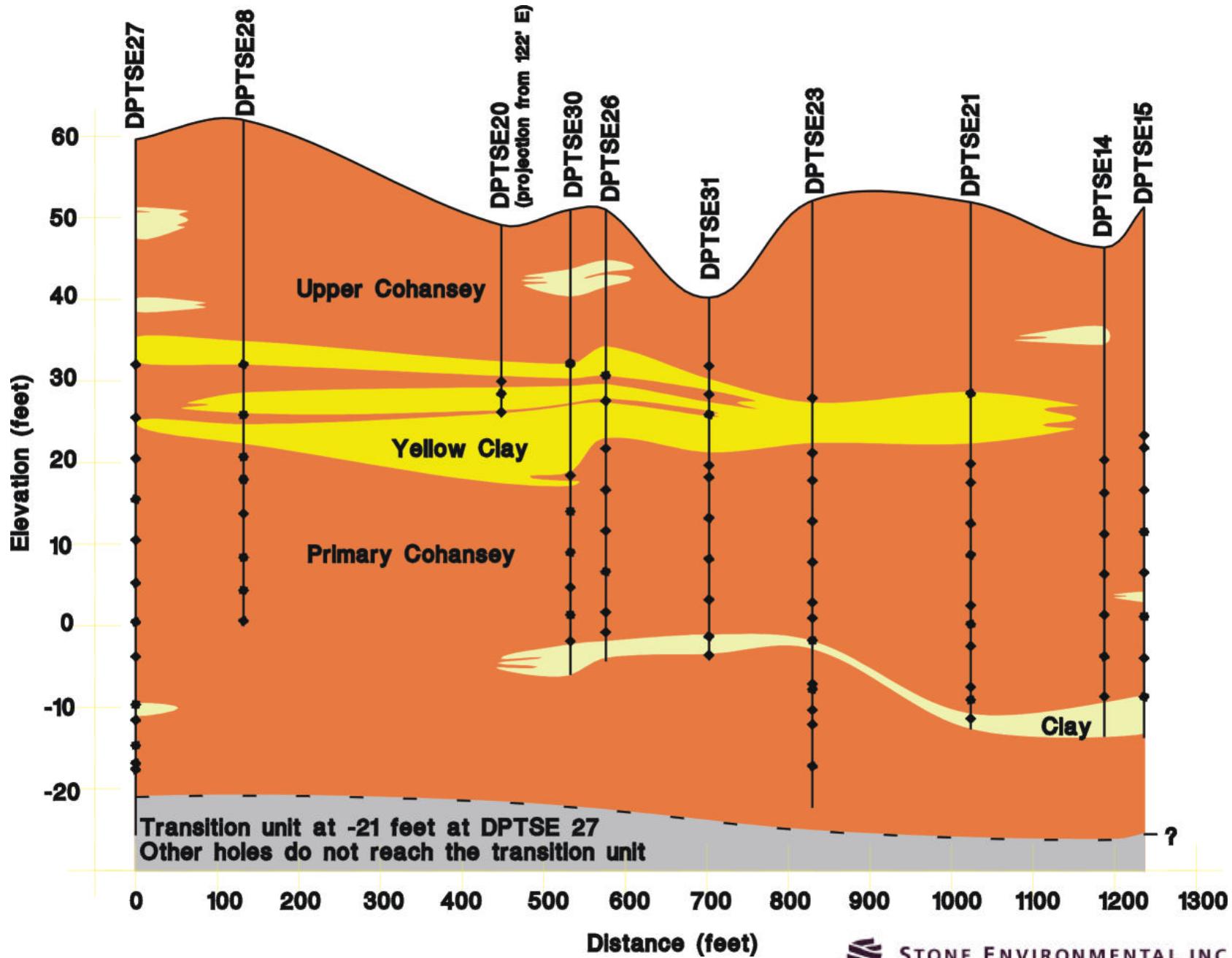
Index of Hydraulic Conductivity (Unitless)



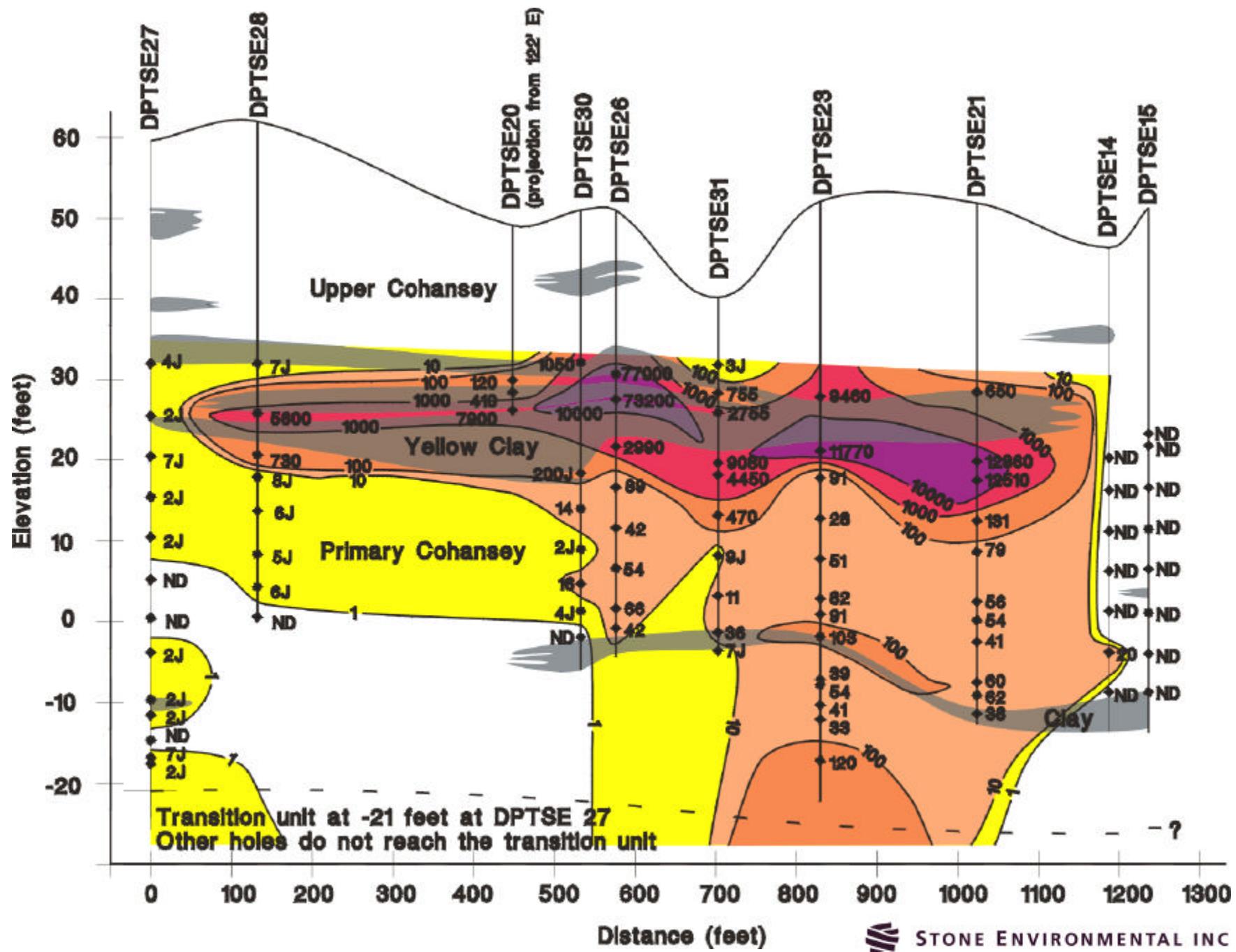


3-D Stratigraphy Models from I_k data



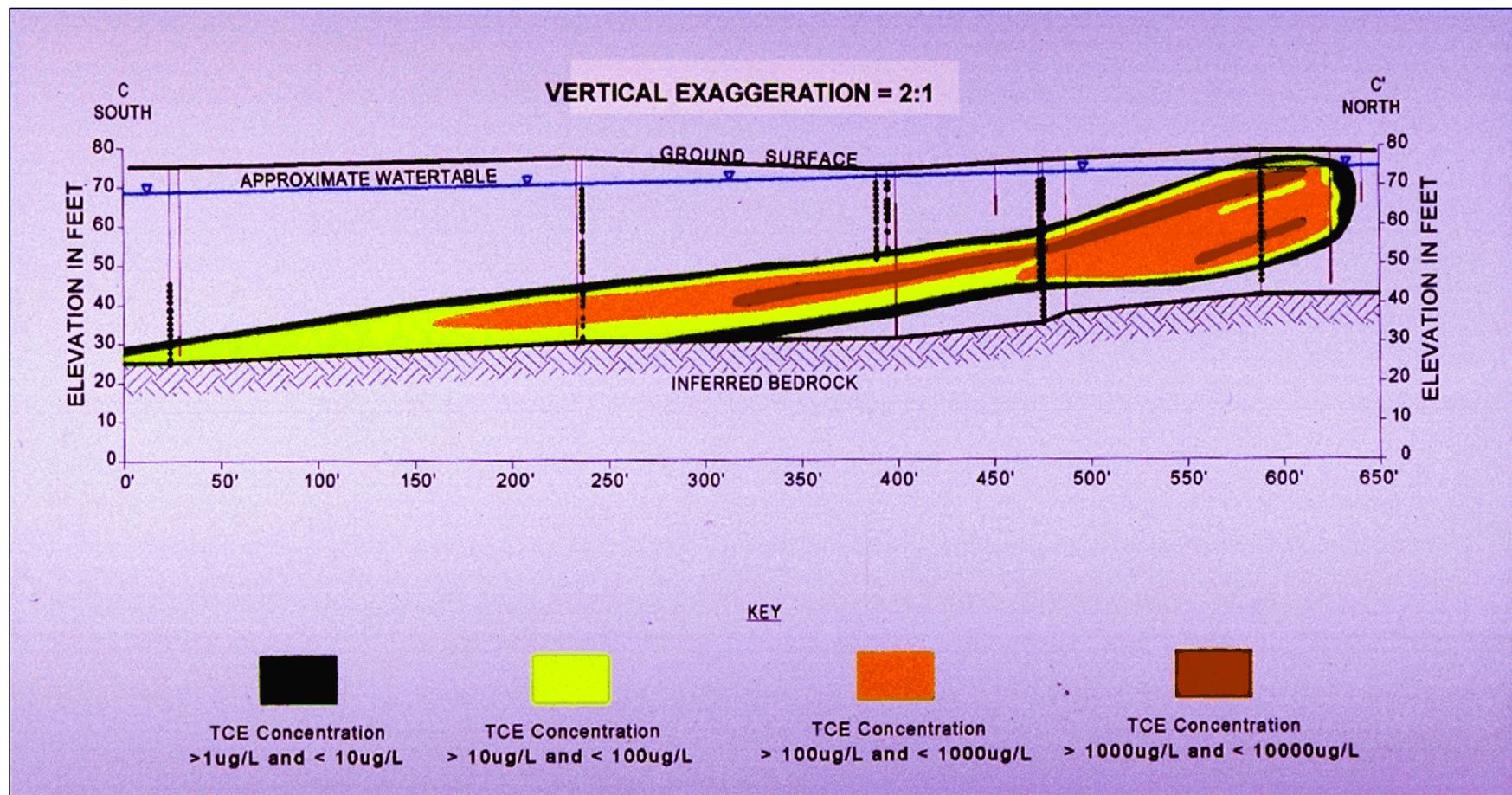


STONE ENVIRONMENTAL INC





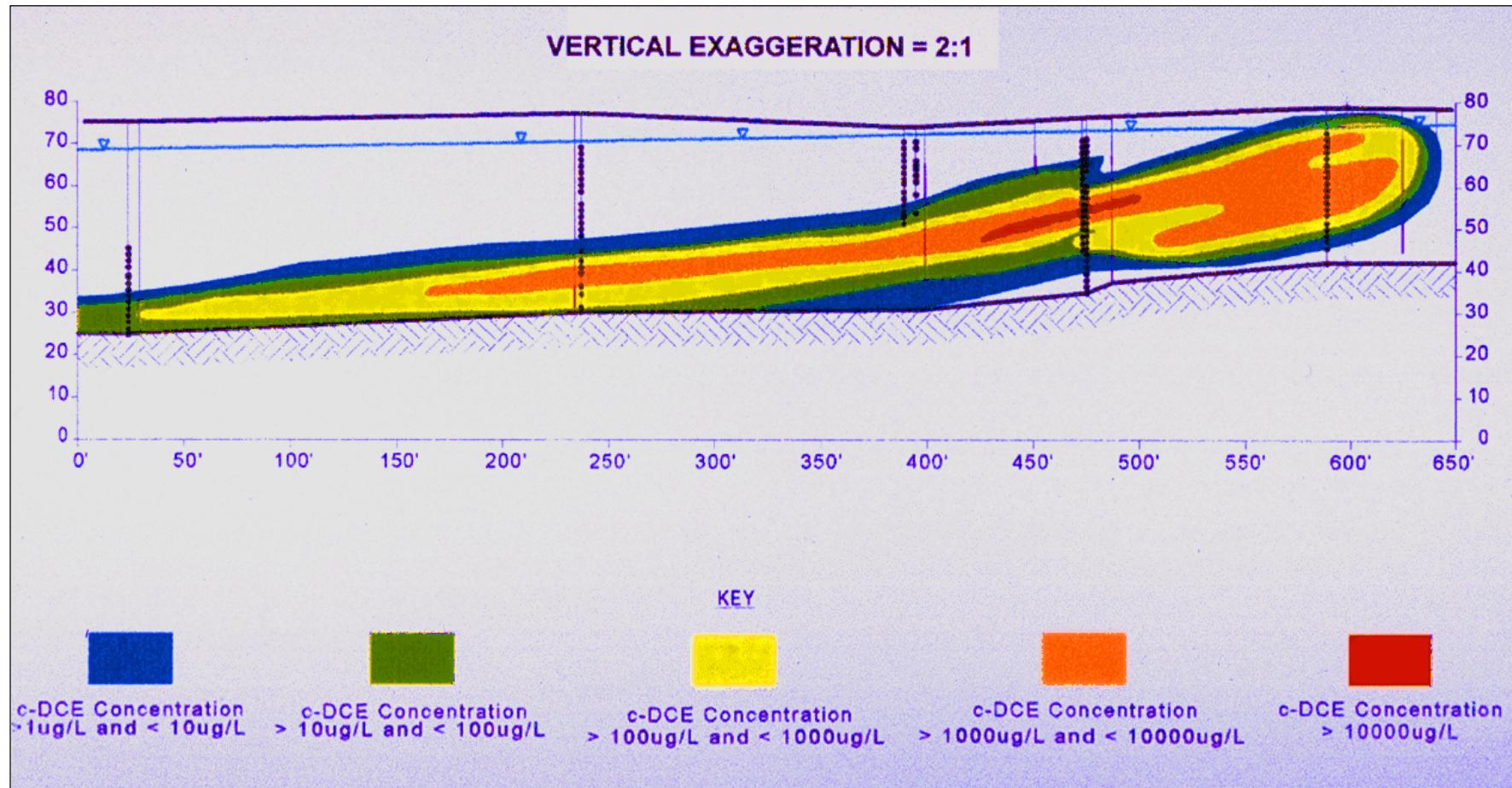
Natural Attenuation of a TCE Plume - Pease AFB Site 73



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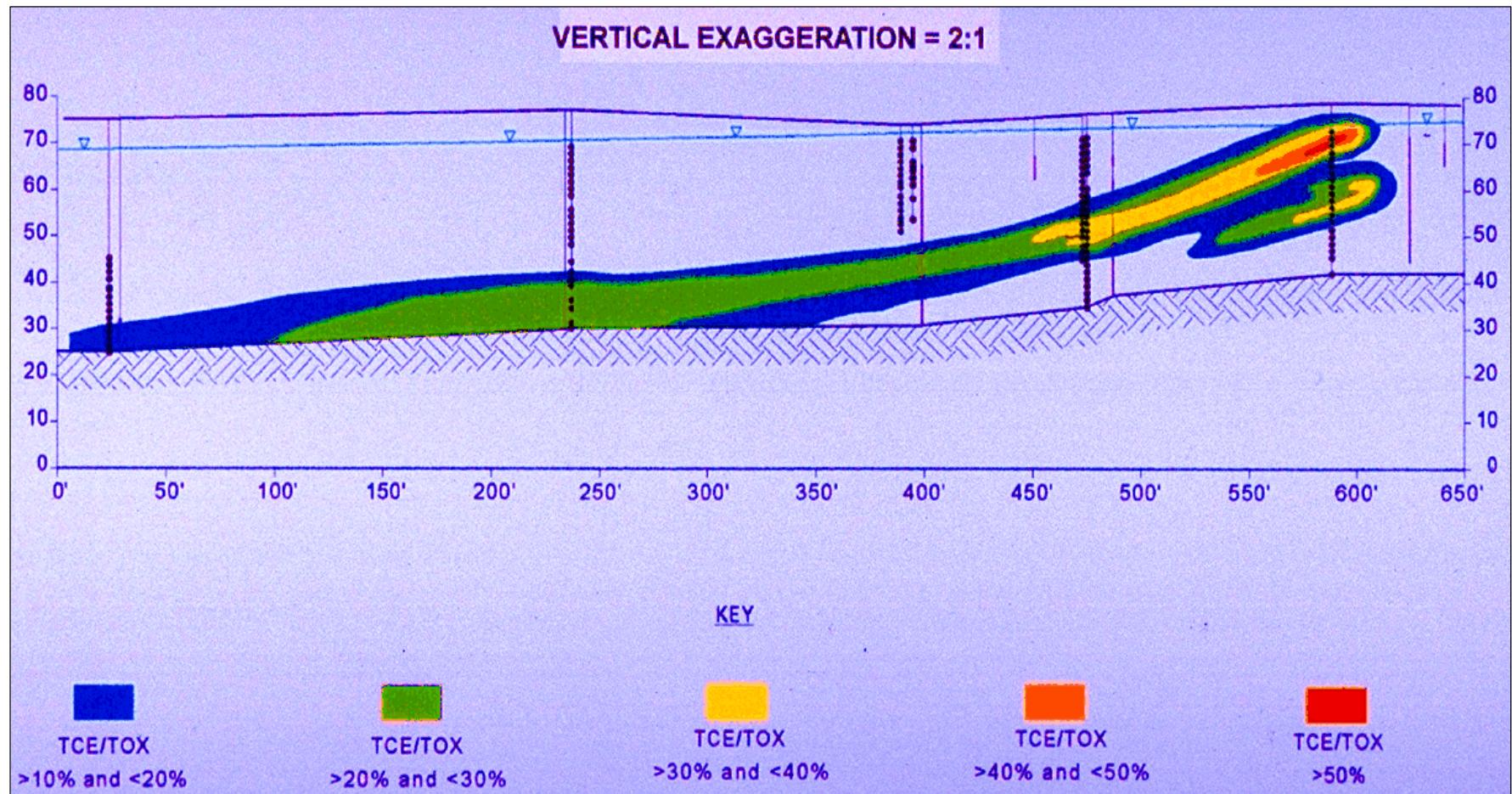
Pease AFB Site 73 c-DCE Plume



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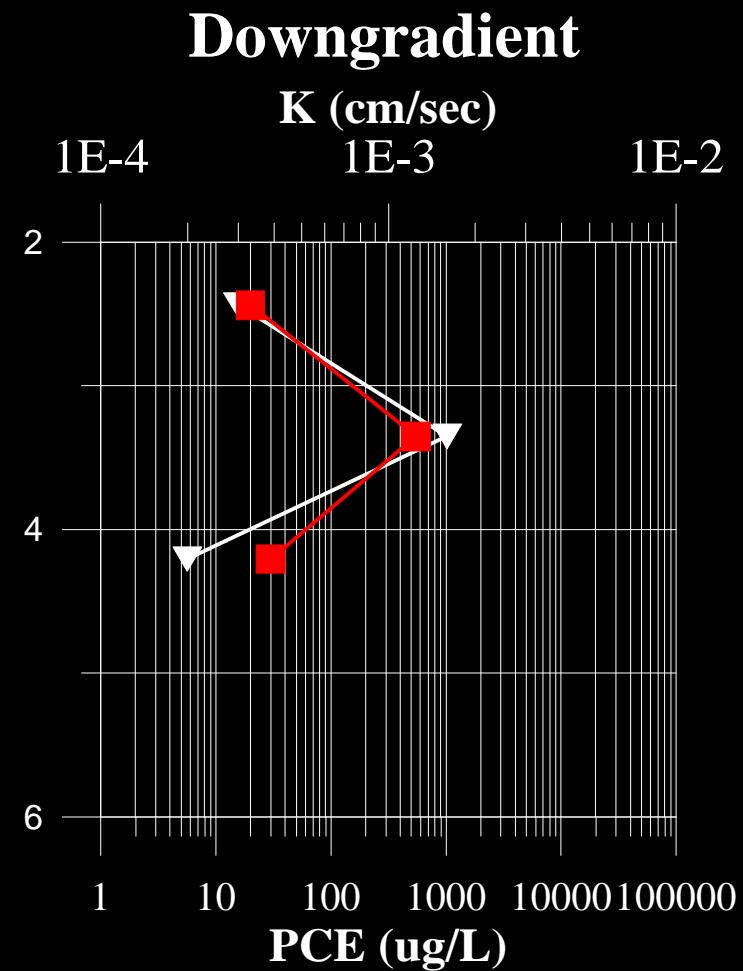
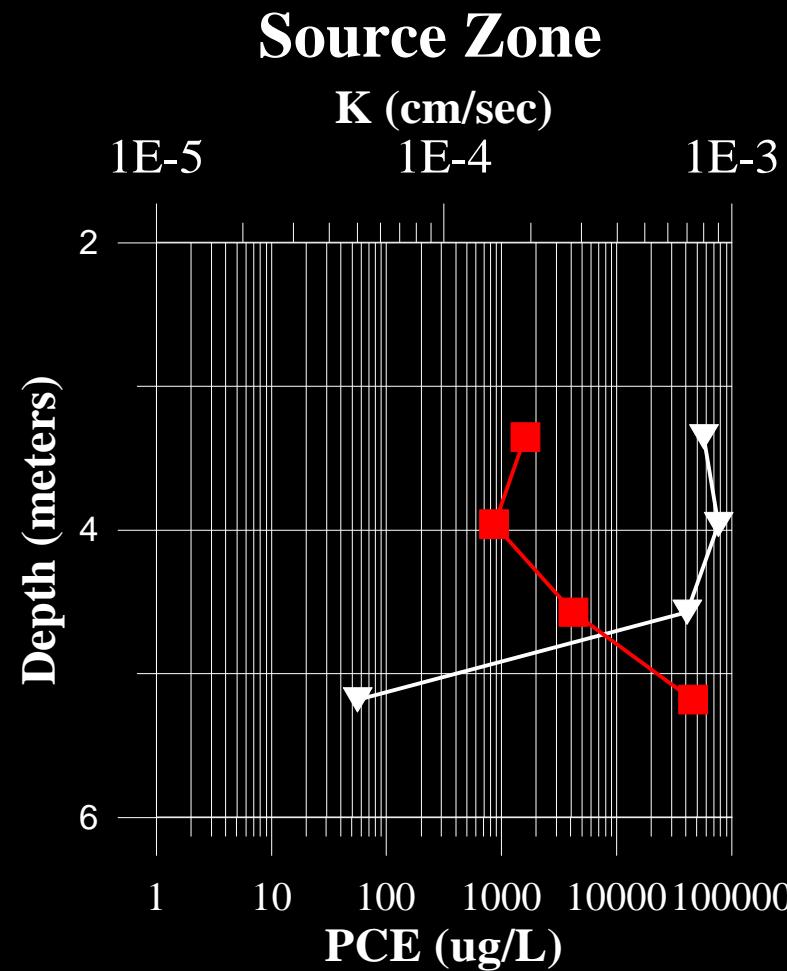
Pease AFB Site 73 Breakdown Product Ratios



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Source Accessibility and Transport Pathways



■ = PCE Concentration

▼ = K hydraulic conductivity cm/sec



Conclusions

- **Hydraulic Conductivity** may vary by orders of magnitude *between* hydrostratigraphic units.
- **Hydraulic conductivity** may vary by orders of magnitude over a few centimeters *within* hydrostratigraphic units.
- Concentration may vary by orders of magnitude over a few centimeters.
- Mass in source areas may be found in low K zones
- Mass transport may occur in very discrete zones
- Detailed site characterizations are essential for successful application of remedial technologies.